Stubble Management Effects on Three Creeping Red Fescue Cultivars Grown for Seed Production

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ABSTRACT

Nonthermal management to mechanically remove residue in creeping red fescue (*Festuca rubra* L.) seed crops has been associated with yield loss when compared with field burning. This 2-yr field study was conducted to investigate the underlying causes for reduced seed yield potential under mechanical residue removal management compared with traditional burning. The effects of two stubble heights, 2.5 and 5.0 cm, complete mechanical stubble removal, and burning were measured on three cultivars of creeping red fescue stands during the first, second, and third year after establishment. Plant reserves for regrowth were reduced by an average of 47% over all cultivars when stubble was completely removed by burning or mechanically below 5.0 cm. Fall regrowth in stubble >2.5 cm in height ranged from 0.6 to 1.9 cm taller compared with treatments where stubble was completely removed. Fall tiller height showed a consistent negative relationship with fertile tiller production in the following spring. Rhizome development in 'Shademaster' and 'Hector', which produce many rhizomes, was reduced >30% when stubble was removed below 2.5 cm. Fertile tiller production, a major component of creeping red fescue yield potential, increased by >25% when stubble was removed by burning or mechanically to ground level in both Shademaster and Hector but was unaffected in 'Seabreeze', which produces few rhizomes. In seed production of creeping red fescue, stubble removal to the plant crown, particularly in cultivars producing many rhizomes, is crucial for maximizing seed yield potential.

Open-field burning has been used as a successful management tool to remove residue from seed production fields and maintain seed yield and quality in creeping red fescue. Legislated reduction in field burning in Oregon's Willamette Valley has prompted several investigations on the production of grass seed crops without burning crop residues. Young et al. (1998) demonstrated that seed yield in creeping red fescue could not be maintained without burning crop residues. An increased understanding of why seed yield potential in creeping red fescue is reduced when field residue is not burned is needed to develop mechanical stubble-management alternatives.

Removal of all stubble by open burning in Kentucky bluegrass (*Poa pratensis* L.) increased fertile tiller number, large-tiller (>2-mm basal diam.) number, and seed yield and reduced rhizome production compared with clipped stubble (Hickey and Ensign, 1983). Removal of stubble to 2.5 cm after straw was baled from the field reduced fall tiller height and increased fertile tiller num-

ber and overall yield in Kentucky bluegrass (Thompson and Clark, 1989). Using field-scale equipment, Chastain et al. (1995) found that stubble removed to <1.5-cm height generally reduced fall tiller height but did not affect fertile tiller number and that seed yield was comparable to that achieved with open-field burning in Kentucky bluegrass. Stubble removed to <1.5 cm in seed fields of creeping red fescue reduced fall tiller height but resulted in lower fertile tiller number and lower seed yield compared with fields that were burned.

The objective of this study was to investigate the underlying causes for reduced seed yield under thermal and mechanical residue removal management by observing the effects of stubble height on available reserves for fall regrowth, tillering, plant development, and flowering in creeping red fescue.

MATERIALS AND METHODS

This study was conducted in the Willamette Valley of western Oregon during 1995 to 1997. Studies were conducted in a commercial production field of Hector creeping red fescue (Taylor farm) near Sublimity, OR on a Jory silty clay loam (fine, mixed, active, mesic Xeric Palehumults) and on Shademaster and Seabreeze creeping red fescue planted at the Hyslop Research Farm near Corvallis, OR on a Woodburn silt loam soil (fine-silty, mixed, mesic Aquultic, Argixerolls). Hector and Shademaster are classified as *Festuca rubra* var. *rubra* (2n = 56 chromosomes) and are spread from strong underground stems (Alderson and Sharp, 1995). Seabreeze is classified as *F. rubra* var. *litoralis* Vasey (2n = 42 chromosomes), a slender creeping red fescue (Rose-Fricker et al., 1999). Slender creeping red fescue typically forms reduced rhizomes (Summers, 1998).

Experimental units were managed as part of the entire production field at the Taylor farm and a similar practice was used at Hyslop Research Farm. Weeds were controlled by fall and winter applications of labeled herbicides as needed. Thirty-three to 44 kg ha^{-1} N and K, respectively, and 44 to 61 kg P ha^{-1} were applied in the fall following stubble treatments of each production year. A second application of 100 to 112 kg N ha^{-1} was applied during March each year. The experimental design was a randomized complete block with three replicates at both locations. Treatments were fixed effects of burning and three stubble heights imposed after harvest: ground level (GL), 2.5 cm, and 5.0 cm. Treatments were assigned within blocks at random with the exception of the burn treatment. The burn treatment was established directly adjacent to the mechanical treatments at each location because of the difficulty in burning within the mechanical treatment and the potential effects of fire on the mechanical residue-removal treatments.

Experimental units were 1 m^2 (three rows wide) and established in the fall of 1995 at both locations. Experimental units at Hyslop Research Farm were planted using C-banding techniques as described by Lee (1973). Data were taken at the

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Abbreviations: GL, ground level.

Taylor farm during 1996 and 1997 in the second and third seed production years for that field and at Hyslop Research Farm during 1996 and 1997 in the first and second seed production years. All samples were taken from locations within plots determined by random drop of a 15-cm² quadrant. Sample sites within plots were not revisited, and the quadrant moved sufficient distance during subsequent sampling to prevent overlap.

Stubble Height Treatments

Stubble removal treatments were applied to the experimental units at each location immediately after seed harvest. The GL stubble heights were imposed using a gasoline-powered brush cutter with a rotating metal, three-edged blade to remove all vegetative material to the crown. A sickle-bar mower with a 1-m cutting edge was used for the 2.5- and 5.0-cm stubble heights above the crown. The crown is defined as a region of compressed nodes and internodes just below the soil surface from which axillary tillers arise (Turgeon, 1999). Residue was removed from experimental units with a hand rake following the stubble-cutting treatment. Postharvest residue and stubble was burned from the surface of each burn treatment plot for each of three replications at each location at the same time as the mechanical treatments.

Plant Reserves for Regrowth

Plant reserves were estimated from grams of regrowth dry matter using techniques described by Burton et al. (1962) and Burton (1995). This method provides general quantification of reserves and requires no chemical analysis. Immediately following stubble treatments, root and rhizome connections with surrounding plants were severed by inserting a 10.2-cm-diam. coring tool 15 cm deep within each experimental unit. This was done to prevent translocation of water or photosynthate from surrounding plant material. Roots within and below the 15-cm-deep core remained intact to allow water uptake by the isolated plants. To exclude light, a PVC pipe 10.2 cm in diam. and 35 cm long with a black interior was placed over plants and inserted 5 cm into the soil. Tubes were sealed with the exception of a 1-cm-diam. ventilation pipe extending out perpendicularly 2.5 cm near the top of the tube. Etiolated tissue from plants within the tubes was harvested every 30 d from the time of initial tube placement until no further regrowth was produced and dried for 24 h at 60°C. Dry matter regrowth was measured as the cumulative dry weight of the etiolated regrowth from each light restriction tube.

Fall Tiller Regrowth and Development

Each year between 10 January and 31 March, a sod sample 15 by 15 by 5 cm deep was taken from each experimental unit following regrowth. Sod samples were taken over time by sampling an entire replication within each cultivar. Sequential sampling was required due to restrictions in storage and handling of living tissue during data collection. Sod samples were placed in a cooler at 0 to 5°C until tiller data could be collected from each core. Samples were taken individually from cold storage, and tillers were removed from the core for data collection. Tiller regrowth height was measured from the crown to the tip of the longest leaf. Developmental stages were estimated according to a modified Haun stage (Klepper et al., 1982). Tiller diameters were measured at the base just above the point of attachment to the crown and sorted by basal diameter in 1-mm increments. Total tiller number and vegetative dry weight after drying for 36 h at 60°C were determined on each sample.

Root and Rhizome Dry Weight

Soil cores were taken from each experimental unit in March each year using a standard golf-course cup cutter (10.2 cm diam.) with a core volume of 294.5 cm³. Soil was washed from each sample, roots and rhizomes separated by hand, and samples dried for 36 h at 60°C. Dry weights were determined and rhizome/root weight ratios calculated.

Fertile Tillers

A second sod sample was taken from each experimental unit in the spring immediately after anthesis. Vegetative and fertile tillers were separated based on the presence or absence of emerged inflorescences. These two groups of tillers were counted, and the percentage of fertile tillers was calculated. Samples were dried for 36 h at 60°C, and total vegetative dry weights were determined for each treatment. Based on research by Chastain and Grabe (1988), Fairey and Lefkovitch (1996), and Young et al. (1998), the percentage of fertile tillers is a reliable estimator of yield potential in creeping red fescue, and thus was used in this study.

Experimental Analysis

Analysis of variance was used to determine if significant differences existed among treatments, and linear regression was used to investigate relationships between data as outlined by SAS (SAS Inst., 1990). Mean separations were conducted using Fisher's protected least significant difference (LSD; $P = 0.05$).

RESULTS

The analysis of variance over years indicated that year was significant and that numerous interactions occurred with year. Therefore, the results are presented for each cultivar production year. Cultivars could not be combined in analysis because of the different production locations used in the study.

Plant Reserves for Regrowth

Plant reserves, as measured by regrowth, were reduced in five of the six cultivar years in the burn treatment and when stubble was mechanically removed to stubble heights of GL and 2.5 cm compared with 5.0 cm (Table 1). Reductions in both tiller number and vegetative mass contributed to the reduced dry weight of etio-

Table 1. Effect of stubble height treatment (SHT) (mechanical removal or burning) on etiolated dry matter regrowth in various aged stands of three cultivars of creeping red fescue.

SHT	Shademaster		Hector		Seabreeze	
	1st year†	2nd year	2nd year	3rd year	1st year	2nd year
	g m⁻²					
Burn	1.244a‡	24.854b	10.793a	16.085b	0.582a	0.427a
GL§	3.037b	16.012a	13.012a	5.561a	0.232a	0.000a
2.5 cm	2.939b	14.951a	13.500a	2.793a	0.329a	0.000a
5.0 cm	4.890c	18.537ab	22.378b	27.768c	10.793b	7.524b
LSD	0.731	7.000	3.939	3.183	1.085	1.390

† The 1996 and 1997 production years for Shademaster and Seabreeze were first- and second-year stands, respectively. The 1996 and 1997 production years for Hector were second- and third-year stands, respectively.

‡ Means in a column are not different by Fisher's LSD values ($P = 0.05$) when followed by the same letter.

§ GL, ground level.

Table 2. Effect of stubble height treatment (SHT) (mechanical removal or burning) on mean regrowth height of fall tillers and mean developmental stage of tillers in three cultivars of creeping red fescue.

SHT	Shademaster		Hector		Seabreeze	
	1st year†	2nd year	2nd year	3rd year	1st year	2nd year
			Regrowth height, cm			
Burn	14.7b‡	8.4a	10.2a	7.2b	9.7b	7.3bc
GL§	12.7a	9.0a	9.9a	6.2a	8.5a	6.3a
2.5 cm	15.3b	9.0a	11.7b	8.0c	11.4c	7.1b
5.0 cm	14.8b	10.2b	11.7b	8.4c	11.4c	7.6c
LSD	1.0	0.8	0.8	0.5	1.0	0.5
			Developmental stage¶			
Burn	2.8b	2.8b	2.7a	2.0a	2.5a	2.9b
GL	2.5a	2.5a	2.8a	2.1b	2.6b	2.8ab
2.5 cm	2.6a	2.6a	2.5a	2.3c	2.5a	2.8ab
5.0 cm	2.5a	2.6a	2.5a	2.4c	2.5a	2.7a
LSD	0.20	0.21	0.65	0.15	0.20	0.20

† The 1996 and 1997 production years for Shademaster and Seabreeze were first- and second-year stands, respectively. The 1996 and 1997 production years for Hector were second- and third-year stands, respectively.

‡ Means in a column are not different by Fisher's LSD values ($P = 0.05$) when followed by the same letter.

§ GL, ground level.

¶ Developmental stage is determined by the number of fully emerged leaves plus the length (in tenths) of the next emerging leaf in relative length to the most recent fully emerged leaf.

Table 3. Effect of stubble height treatment (SHT) (mechanical removal or burning) on fall tiller number and percentage of large tillers (basal diam. >2 mm) in three cultivars of creeping red fescue.

SHT	Shademaster		Hector		Seabreeze	
	1st year†	2nd year	2nd year	3rd year	1st year	2nd year
			Fall tiller number, m^{-2}			
Burn	14 711c‡	24 044ab	19 467a	16 311a	18 622a	31 200b
GL§	8 133a	25 689b	18 222a	17 378a	14 356a	34 711c
2.5 cm	10 933b	23 111a	18 089a	16 311a	16 444a	15 956d
5.0 cm	10 311b	22 844a	18 222a	17 111a	15 733a	27 689a
LSD	1 689	2 444	2 578	2 044	5 200	2 800
			% Large tillers			
Burn	88b	87c	69a	57b	80a	69c
GL	85b	68ab	61a	48a	76a	53b
2.5 cm	77a	61ab	67a	52ab	69a	53b
5.0 cm	77a	57a	65a	56ab	71a	43a
LSD	5	11	7	8	11	9

† The 1996 and 1997 production years for Shademaster and Seabreeze were first- and second-year stands, respectively. The 1996 and 1997 production years for Hector were second- and third-year stands, respectively.

‡ Means in a column are not different by Fisher's LSD values ($P = 0.05$) when followed by the same letter.

§ GL, ground level.

lated tissue produced from these isolated crowns (data not shown).

Fall Regrowth and Development

Fall tiller regrowth of all three cultivars was shorter when stubble was mechanically removed to GL than when removed to 2.5 or 5.0 cm, with the exception of Shademaster during the second production year (Table 2). Stubble height treatments did not consistently affect the mean developmental stage of regrowth in this study (Table 2).

Fall tiller number was variable across stubble height treatments, with the exception of Hector, for which no differences were detected in each production year (Table 3). Burned plots produced a greater percentage of large tillers (>2-mm basal diam.) than those with mechanical stubble height treatments in second-year Shademaster, third-year Hector, and second-year Seabreeze (Table 3). The burn treatment was not different from the GL treatment in other production years within each cultivar.

Root and Rhizome Development

Root dry weight was greatest under the burn treatment for each cultivar in the second production year compared with mechanical stubble removal (Table 4). There were no significant differences among treatments in the third-year Hector stand, and first-year stands of Shademaster and Seabreeze were variable for root dry weight (Table 4). Rhizome dry weight was reduced in the burn and GL stubble treatments compared with 2.5- and 5.0-cm treatments in first-year stands of Shademaster and Seabreeze and in the third-year stand of Hector (Table 4). When stubble remained above GL, rhizome weights were not different than when stubble was re-

moved by burning in the second-year Seabreeze stand (Table 4).

Fertile Tillers

The Shademaster first- and second-year stands and the Hector second-year stand produced a lower percentage of fertile tillers under stubble that was 2.5 cm or taller (Table 5). Fertile tiller production in the second-year stand of Seabreeze was not different for any of the stubble treatments (Table 5).

Regrowth height of fall tillers following stubble height treatments showed a consistent negative relationship with the percentage of fertile tiller production the following spring (Fig. 1). As tillers originating in the fall became more elongated, they were less likely to be induced to flower the following spring. Tillers originat-

Table 4. Effect of stubble height treatment (SHT) (mechanical removal or burning) on root dry weight and rhizome dry weight in three cultivars of creeping red fescue.

SHT	Shademaster		Hector		Seabreeze	
	1st year†	2nd year	2nd year	3rd year	1st year	2nd year
			Root dry weight, g m^{-2}			
Burn	9 616ab‡	73 191b	13 761b	10 941a	9 990b	38 803b
GL§	8 393a	36 629a	9 477a	12 198a	6 184a	25 620a
2.5 cm	13 252c	41 658a	10 432a	14 101a	10 092b	29 732a
5.0 cm	12 029bc	43 595a	10 159a	14 781a	9 106b	25 994a
LSD	2 684	18 688	2 480	4 723	1 529	6 898
			Rhizome dry weight, g m^{-2}			
Burn	646a	1 087a	1 937ab	1 053a	34a	748b
GL	544a	1 359a	1 597a	1 257a	34a	136a
2.5 cm	1 835b	1 019a	2 277b	2 107b	815c	510b
5.0 cm	1 529b	1 393a	2 311b	2 277b	510b	544b
LSD	374	578	544	612	272	339

† The 1996 and 1997 production years for Shademaster and Seabreeze were first- and second-year stands, respectively. The 1996 and 1997 production years for Hector were second- and third-year stands, respectively.

‡ Means in a column are not different by Fisher's LSD values ($P = 0.05$) when followed by the same letter.

§ GL, ground level.

Table 5. Effect of stubble height treatment (SHT) (mechanical removal or burning) on the percentage of fertile tiller number in three cultivars of creeping red fescue.

SHT	Shademaster		Hector		Seabreeze	
	1st year†	2nd year	2nd year	3rd year	1st year	2nd year
			% Fertile tillers			
Burn	16ab‡	44c	53b	64b	28b	32a
GL§	17b	31b	52b	61b	19a	32a
2.5 cm	15a	22a	39a	53a	21a	33a
5.0 cm	13a	19a	38a	58ab	21a	30a
LSD	3	5	7	6	4	7

† The 1996 and 1997 production years for Shademaster and Seabreeze were first- and second-year stands, respectively. The 1996 and 1997 production years for Hector were second- and third-year stands, respectively.
‡ Means in a column are not different by Fisher's LSD values ($P = 0.05$) when followed by the same letter.
§ GL, ground level.

ing in the spring did not receive the vernalization requirements of creeping red fescue (Meijer, 1984; Heide, 1994), and therefore did not contribute to fertile tiller number.

DISCUSSION

Determination of energy available for regrowth using techniques described by Burton et al. (1962) and Burton (1995) showed that regrowth was affected by the presence of stubble in the field after seed harvest (Table 1), but the effect may also include a genetic predisposition to rhizome production in each cultivar. For instance, Seabreeze exhibits a genetic predisposition to produce few rhizomes (Rose-Fricker et al., 1999), and the reduction in stubble height below 5.0 cm greatly reduced etiolated regrowth, suggesting that energy resources were remobilized from stubble tissue to the crown before complete senescence. This is possible because the seed crop is swathed for harvest while the culm is green and stubble remains photosynthetic through harvest and
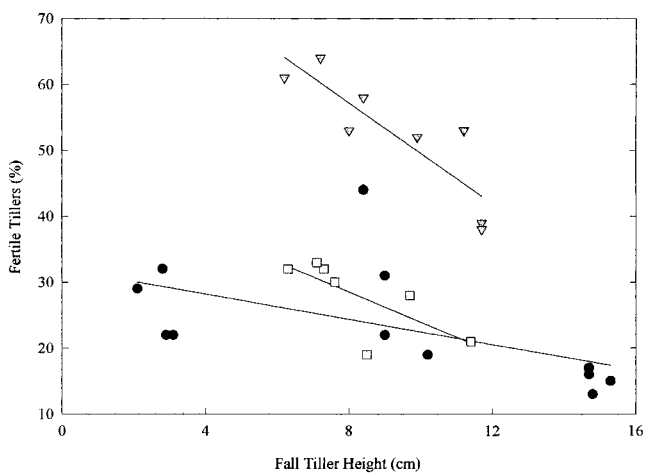

Fig. 1. Relationship of fall tiller regrowth height to the percentage of fertile tillers in three cultivars of creeping red fescue. Regression equations for the fitted line for each cultivar are Shademaster, $Y = 32.01 - 0.95X$, $r^2 = 0.30$, $P < 0.10$, and root mean square error (RMSE) = 6.51; Seabreeze, $Y = 46.72 - 2.28X$, $r^2 = 0.61$, $P < 0.05$, and RMSE = 7.38; and Hector, $Y = 87.84 - 3.83X$, $r^2 = 0.76$, $P < 0.01$, and RMSE = 6.75.

stubble management. Volenec (1986) reported similar results for tall fescue (*F. arundinacea* Schreb.) clipped to 7.5 cm compared with unclipped tillers. Ackerson and Chilcote (1978) reported that clipping Kentucky bluegrass below 2.5 cm caused the greatest reduction in water-soluble carbohydrate concentration in stem bases compared with 5.0-cm stubble or an unclipped control. Shademaster and Hector produce considerably more rhizomes and had greater reserves available for regrowth; however, dry matter reserves were also reduced when stubble was mechanically removed below 5.0 cm but not when the burn treatment was applied. Nyahoza et al. (1973) reported that rhizomes appeared to supply carbohydrates for regrowth after defoliation in Kentucky bluegrass, and this is likely the case here as well. Remobilization from stubble as well as the inherent genetic differences in rhizome production of each cultivar tested may account for changes in available dry matter reserves found in this study.

The presence of stubble after harvest generally caused tillers to be more elongated but did not affect the developmental stage of tillers during the fall regrowth period (Table 2). Chilcote et al. (1974) reported that fall tiller regrowth of creeping red fescue was shorter when straw and stubble were removed by burning. Similar results have been reported in Kentucky bluegrass (Hickey and Ensign, 1983; Ensign et al., 1983). The regrowth height of fall tillers has been shown to be negatively correlated with flowering and yield potential in Kentucky bluegrass (Chastain et al., 1997). The cause of differences in the regrowth height of fall tillers was not demonstrated in our study.

The burn treatment resulted in a greater percentage of large tillers (>2.0 mm) than the mechanical stubble-removal treatments in the second-year crop of Shademaster and Seabreeze (Table 3). The ability of tillers to be induced to flower has been associated with a minimum basal diameter of 2.0 mm in Kentucky bluegrass (Canode and Law, 1979; Hickey and Ensign, 1983; Chastain et al., 1997), but we did not find a similar relationship in creeping red fescue (data not shown). Although burning removes all available aboveground reserves from the plant, it is likely that complete removal by mechanical means sufficiently disturbed or damaged axillary meristems such that tillers were delayed in development, as evidenced by a tendency to be shorter under this treatment. This reduction in development was also observed in a general trend towards a greater percentage of large tillers in the burn treatment, particularly as each stand aged.

Mechanical stubble removal, especially below 2.5 cm, tended to reduce the root dry weight to a greater extent than the burn treatment (Table 4), which was similar to that reported by Chilcote et al. (1980). Significant loss of root mass might be detrimental to plant survival, but neither the burn treatment nor the mechanical stubble-removal treatments showed any observable loss of stand in this study. Of greater significance is the change in rhizome production under the various treatments. The perennial nature of creeping red fescue arises from initiation of new tillers from crown axillary meristems

or ramets arising from rhizomes initiated from crown meristems. Establishment of new ramets during fall regrowth would provide competition for reserves available for tiller establishment. Practices that reduce the number of rhizomes could change resource allocation for the establishment of tillers. If so, survival may be assured by seed production rather than by the balance of seed and ramet production found in natural swards. Rhizome production creates good turf strength but is inversely related to seed production in Kentucky bluegrass (Chilcote and Ching, 1973), which exhibits a growth habit similar to creeping red fescue. Ensign and Weiser (1975) found that continuous mowing during floral initiation in Kentucky bluegrass and creeping red fescue resulted in increased root and rhizome production, indicating a balance between flowering and rhizome establishment.

In this study, both the burn treatment and mechanical removal of stubble to GL reduced rhizome production compared with stubble height of 2.5 cm or greater in all but one cultivar-year (Table 4), which is similar to that reported in Kentucky bluegrass (Hickey and Ensign, 1983). Destruction of rhizomes by heat does not necessarily explain the lower rhizome weight in the burn treatment because the GL stubble treatment also reduced rhizome production compared with the 5.0-cm treatment. A better explanation may be the reallocation of resources toward tiller production due to complete stubble removal (Table 3) and subsequent initiation of tillers rather than rhizomes, with differentiation controlled at the crown axillary meristems.

Most research indicates that fertile tiller number is the most important component of seed yield potential in creeping red fescue and is closely associated with seed yield (Chastain and Grabe, 1988; Fairey and Lefkovitch, 1996; Young et al., 1998). Seed yield potential in creeping red fescue (as measured by fertile tiller number) tended to be greater when stubble was completely removed either mechanically or by burning in Shademaster and Hector, which produce greater numbers of rhizomes than Seabreeze (Table 5). Greater production of fertile tillers in cool-season grasses has generally been associated with field burning (Chilcote et al., 1980; Hickey and Ensign, 1983; Chastain et al., 1995) although Chastain et al. (1997) found that fertile tiller production in Kentucky bluegrass was equivalent to burning when stubble was mechanically removed to <4.1 cm. Removal of all aboveground stubble was necessary to maximize yield potential in our study.

Loss of field burning in seed production of creeping red fescue has created the need to find alternative methods to maintain yield in this crop. Alternative residue-management methods must maximize fall regrowth early in the postharvest period, promote short tiller height during fall regrowth, and reduce the allocation of resources to rhizome production to maintain economic seed yield in this species. Although machinery is not currently available to uniformly remove stubble to the crown on a field scale, results of this study suggest that removal of residue and stubble down to the crown will best mimic the effects of field burning, allowing maximum yield potential in creeping red fescue.

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Estimating Forage Mass with a Commercial Capacitance Meter, Rising Plate Meter, and Pasture Ruler

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ABSTRACT

Accurate assessment of forage mass in pastures is key to budgeting forage in grazing systems. Our objective was to determine the accuracy of an electronic capacitance meter, a rising plate meter, and a pasture ruler in measuring forage mass and to determine the cost of measurement inaccuracy. Forage mass was estimated in grazed pastures on farms in Pennsylvania, Maryland, and West Virginia in 1998 and 1999. Forage mass estimated by each method was compared with forage mass estimated by hand-clipped samples. None of these indirect methods were accurate or precise, and error levels ranged from 26 to 33% of the mean forage mass measured on the pastures. The computer model DAFOSYM (Dairy Forage System Model) was used to simulate farm performance and the resulting effects of inaccuracies in estimating forage mass on pasture. A representative grazing dairy farm was developed, and the costs and returns from low-input and conventional managements were calculated. Different scenarios were then simulated, including under- or overestimating forage yield on pastures by 10 or 20%. All scenarios simulated resulted in lower returns compared with the optimum farm, with decreases in net return ranging from \$8 to \$198 ha^{-1} yr^{-1}. Underestimating forage mass resulted in less hay and silage being harvested, more pasture being consumed, and more forage purchased compared with the optimum scenario. The opposite occurred for overestimation of forage mass. Our results indicate that achieving greater accuracy (to within 10% of actual pasture yield) in estimating pasture yields will improve forage budgeting and increase net returns.

Aᴄᴄᴜʀᴀᴛᴇ ʙᴜᴅɢᴇᴛɪɴɢ ᴏꜰ ꜰᴏʀᴀɢᴇ in grazing systems requires frequent assessment of forage mass in pastures. The standard method of assessing forage mass is to clip and weigh the forage. This method requires great effort and expense to collect enough samples to accurately represent a pasture, and farmers are not willing to make this effort in day-to-day management of pastures. Researchers commonly use double-sampling techniques to increase the precision of pasture sampling, and thus reduce labor and dollar expense (Frame, 1993). During the past 70 yr, many methods have been evaluated from simple rulers to sophisticated electronic meters (Lucas and Thomson, 1994). Some methods have been adapted for commercial use, including the electronic capacitance meter, rising plate meter, and simple pasture ruler.

The electronic capacitance meter relies on differences in dielectric constants between air and herbage. The meter measures the capacitance of the air–herbage mixture (Curie et al., 1987) and responds mainly to the surface area of the foliage (Vickery and Nicol, 1982). The rising plate meter integrates sward height and density into one measure, often called bulk height or bulk density (Michalk and Herbert, 1977). Pasture rulers rely on a positive relationship between forage yield and canopy height.

Commercially available meters come with factory calibrations; however, the accuracy and precision of these equations have not been evaluated for Northeast pasture conditions. Many studies of double-sampling techniques have shown that these techniques require frequent calibration and that *universal* equations for estimating pasture mass may be unreliable (Frame, 1993).

The level of error in measuring forage mass varies widely; however, Rayburn and Rayburn (1998) and Unruh and Fick (1998), working in pastures of the northeast USA, obtained calibration errors with plate meters of about 10% of pasture yields. They concluded that this level of error is acceptable for farm use. It is not known, however, what the economic consequences are of this level of error on a whole-farm basis. Farm data are not available to determine the level of inaccuracy that is economically acceptable. This type of research is expensive to conduct.

Whole-farm simulation models provide an alternative method to estimate economic consequences. The computer simulation model DAFOSYM (Dairy Forage System Model) is a whole-farm model where crop production, feed use, return of manure nutrients back to the land, production costs, income, and net return or profit of representative farms are simulated over many years of weather (Rotz et al., 1989; Rotz et al., 1999). Growth and development of alfalfa (*Medicago sativa* L.), grass, corn (*Zea mays* L.), and other crops are predicted on a daily time step from soil and weather conditions. Functions from the GRASIM (Grazing Simulation Model) model developed and validated by Mohtar et al. (1997a,b) are used to simulate pasture production. This mechanistic model simulates photosynthetic rate and carbohydrate production as a function of solar radiation level,

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Abbreviations: DM, dry matter; SEP, standard error of prediction.